

NASA'S SPACE LAUNCH SYSTEM:
ONE VEHICLE, MANY DESTINATIONS

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The National Aeronautics and Space Administration's (NASA) Space Launch System (SLS) Program, managed at the Marshall Space Flight Center, is making progress toward delivering a new capability for exploration beyond Earth orbit (BEO). Developed with the goals of safety, affordability and sustainability in mind, SLS will start with 10 percent more thrust than the Saturn V rocket that launched astronauts to the Moon 40 years ago. From there it will evolve into the most powerful launch vehicle ever flown, via an upgrade approach that will provide building blocks for future space exploration and development. The International Space Exploration Coordination Group, representing 12 of the world's space agencies, has worked together to create the Global Exploration Roadmap, which outlines paths towards a human landing on Mars, beginning with capability-demonstrating missions to the Moon or an asteroid. The Roadmap and corresponding NASA research outline the requirements for reference missions for all three destinations. This paper will explore the requirements needed for missions to BEO destinations, and the capability of SLS to meet those requirements and enable those missions. It will explain how NASA will execute this development within flat budgetary guidelines by using existing engines assets and heritage technology, from the initial 70 metric ton (t) lift capability through a block upgrade approach to an evolved 130-t capability. The SLS will offer a robust way to transport international crews and the air, water, food, and equipment they would need for extended trips to asteroids, the Moon, and Mars. In addition, this paper will detail SLS's capability to support missions beyond the human exploration roadmap, including robotic precursor missions to other worlds or uniquely high-mass space operation facilities in Earth orbit. As this paper will explain, the SLS provides game-changing mass and volume lift capability that makes it enhancing or enabling for a variety of unprecedented human and robotic missions.

I. PROGRAM BACKGROUND

Scheduled for a first launch in 2017, the NASA new Space Launch System will serve as a cornerstone for a new era of international human exploration of deep space. Since the NASA Authorization Act of 2010 mandated the development of a heavy lift vehicle¹, rapid progress has been made on the world's first exploration-class launch vehicle since the Saturn V, designed to carry human beings beyond low Earth Orbit (LEO) for the first time since 1972, when the

Apollo Program concluded its sixth and final landing on the Moon.

NASA is developing SLS in parallel with two other exploration systems development efforts – the Orion Multi-Purpose Crew Vehicle (MPCV) Program and the Ground Systems Development and Operations (GSDO) Program (Fig. 1). The Orion MPCV is a four-person spacecraft designed to carry astronauts on exploration missions into deep space. GSDO is converting the facilities at NASA's Kennedy Space Center (KSC) into a next-generation spaceport capable of supporting launches by multiple types of vehicles.

These capabilities are part of a larger NASA strategy of working with commercial partners that will support crew and cargo launches to the

¹ NASA Authorization Act of 2010: http://commerce.senate.gov/public/?a=Files.Serve&File_id=20a7a8bd-50f4-4474-bf1d-f0a6a8824b01

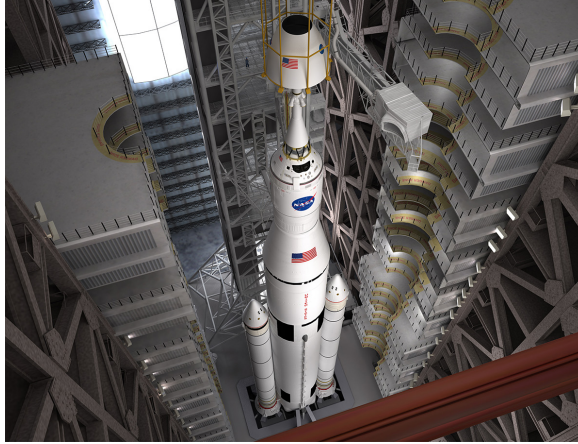


Fig. I: Artist's concept of SLS and Orion in the KSC Vehicle Assembly Building.

International Space Station, while the Agency focuses its development efforts on an incremental approach to developing the systems necessary for human exploration beyond Earth orbit and eventually to Mars. Both Orion and SLS are being designed with enough performance margin and flexibility to support multiple missions and destinations rather than being optimized for one particular mission or architecture.

Following the successful first flight of SLS, the vehicle will then be evolved, eventually reaching a full capability of delivering 130 metric tons to LEO, making it the most powerful launch vehicle ever flown. This evolved configuration, baselined around NASA's Mars Design Reference Architecture studies, is designed to meet the requirements necessary to enable a human mission to Mars. Work is currently underway to do initial engineering studies and risk reduction work to support the evolution of the vehicle. While SLS was chartered for the purpose of supporting human space exploration, the vehicle, in its initial and evolved configurations, will provide a robust capability that can be used to enable a wide variety of high-priority missions.

II. VEHICLE OVERVIEW

Guided by its tenets of safety, affordability, and sustainability, and informed by a mandate to provide a robust vehicle on an aggressive timetable, the Space Launch System Program chose a design that leverages hardware and technology from previous NASA human spaceflight programs, primarily in its propulsion elements (Fig. II).

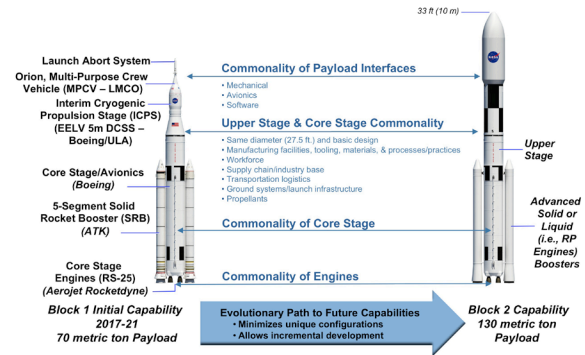


Fig. II: SLS configuration overview.

The SLS Core Stage will be powered by four RS-25 engines, which previously served as the Space Shuttle Main Engine, taking advantage of 30 years of U.S. experience with liquid oxygen (LOX) and liquid hydrogen (LH₂), as well as an existing national infrastructure that includes specialized manufacturing and launching facilities. These human-rated engines support the SLS goal of safety, with a record of 100 percent mission success for the engines over 135 flights. At the end of the Space Shuttle Program, 16 RS-25 engines were transferred to the SLS Program and placed in inventory at NASA's Stennis Space Center, providing enough engines for the first four flights of SLS.

The majority of the thrust at launch for SLS will come from a pair of solid rocket boosters, also of Space Shuttle Program heritage. The SLS Program is leveraging research, development, and testing conducted under the Constellation Program to upgrade the boosters from the four-segment version flown on the Shuttle to a more-powerful five-segment version. During launch, each solid rocket motor will generate up to 3,550,000 lbs. of thrust. Although similar to the SRBs used on the Space Shuttle, this upgraded five-segment SRB includes improvements such as a larger nozzle throat and an environmentally benign insulation and liner. By adding a fourth main engine, versus the three RS-25s flown on Shuttle, and by adding a fifth segment to each of the solid rocket boosters, the initial 70 t version of SLS will generate 8.4 million pounds of thrust at launch.

The SLS LOX/LH₂ core stage will have a diameter of 8.4 meters, sharing commonality with the Space Shuttle's External Tank in order to enhance compatibility with Shuttle-era equipment and

facilities at the Michoud Assembly Facility in Louisiana and at Kennedy Space Center.

In-space propulsion for the 70 t Block 1 version of SLS will be provided by the Interim Cryogenic Propulsion Stage (ICPS), a modified version of United Launch Alliance's Delta Cryogenic Second Stage (DCSS) flown on more than 20 launches of the Delta IV Evolved Expendable Launch Vehicle (EELV). In order to support the currently planned initial test flights that would send the Orion MPCV into circumlunar space, the LH2 tank of the SLS ICPS will be stretched 46 centimeters longer than the standard DCSS (Fig III).

While the SLS Program is primarily focused on first flight, early development work has already begun for the evolution of SLS beyond Block 1. Reaching the full 130 t Block 2 capability will require at least two major new developments, but the SLS evolution approach makes it possible to fly an interim 105-t-class vehicle after the completion of the first of those upgrades. The 105-ton vehicle has been identified as fitting a potential "sweet spot" for the next set of human missions beyond low Earth orbit.

Conceptual development and risk reduction work has already begun on the first of those two upgrades, advanced boosters that will provide a thrust advantage over the Shuttle-heritage solid rocket boosters. This requirement provides a competitive opportunity for industry to deliver cost-effective, innovative hardware for deep-space missions to be conducted after 2021. Through the Advanced Booster Engineering Demonstration and Risk Reduction task, contracts were awarded beginning in 2012 to four industry



Fig. III: Artist's concept of Orion with the SLS interim cryogenic propulsion stage.

teams to perform tasks that could later inform the selection of a design for SLS advanced boosters. One of the contracts, awarded to ATK, involves research into propellant mixes and composite materials for advanced solid rocket boosters. The other three contracts, awarded to Northrop Grumman, Aerojet Rocketdyne, and a team consisting of Dynetics and Aerojet Rocketdyne, focus on a combination of composite structures and engines for liquid hydrocarbon fuel boosters.

The second of the upgrades involves research into upper stage options for the vehicle. While the initial evolutionary path involved use of an upper stage powered by the J-2X engine for ascent and an additional cryogenic propulsion stage for in-space use, evaluations are still being conducted on how best to provide the greatest and earliest mission capture via an upper stage.

Development of either an advanced booster or an upper stage would enable evolution of SLS into a 105-t-class vehicle. At this time, risk reduction work on advanced boosters and trade space evaluation of upper stage options are being conducted concurrently, with a goal of concept maturation to support an evolutionary path decision in 2016 and upgrade to 105 t capability in the early 2020s.

Both the initial 70 t configuration and the later evolved configurations of SLS have the capability to support cargo launches using a payload fairing. While the baseline use of the initial vehicle configuration is crew launch capability, the vehicle is capable in the near-term of supporting cargo launch using existing industry 5 meter fairings, providing a payload environment compatible with extant launch vehicles, but with higher characteristic energy (C3) and greater mass margins. Early research has also been conducted into options for larger 8.4- and 10-m fairings, with which SLS would offer greater payload volume lift capability than any other launch vehicle.

III. STATUS

During the summer of 2013, SLS successfully completed a Preliminary Design Review of its initial configuration, which will provide the capability to deliver 70 metric tons (t) of payload into low Earth orbit, greater than any contemporary launch vehicle. Designed around the values of safety, affordability, and sustainability, SLS leverages heritage hardware

and systems from NASA's previous human space-flight programs, while enhancing those systems to increase the vehicle's performance and utilizing the latest technology to make SLS a truly state-of-the-art capability.

All hardware elements (boosters, main engines, core stage/avionics, and spacecraft and payload integration) have completed their respective PDRs and having achieved a steady cadence of progress. The boosters are currently preparing for qualification motor testing, and the test stand hardware modifications are being finalized for testing of the RS-25 main engines. The first confidence barrel section for the SLS core stage was completed at Michoud Assembly Facility in summer 2013, and an adapter has been completed that will be flown on an Orion test flight aboard a Delta rocket in 2014, using a design that will also be used on SLS-Orion launches.

Progress is also underway on concept development and risk reduction for evolved configurations of SLS. In February 2013, test-firings were conducted of a heritage gas-generator from an Apollo-era F-1 engine, with the results informing research into a modernized F-1B engine that could be a candidate for an advanced liquid-fuel booster for SLS (Fig. IV). Hot-fire testing of the J-2X engine has included a component produced using additive manufacturing.

IV. HUMAN SPACEFLIGHT UTILIZATION

The Space Launch System was authorized with the intent of providing an enabling capability for human exploration into deep space, including, but not limited to, landings on Mars. For missions beyond cislunar space, SLS will be one of several new sys-



Fig. IV: Test-firing of an F-1 gas generator at NASA's Marshall Space Flight Center.

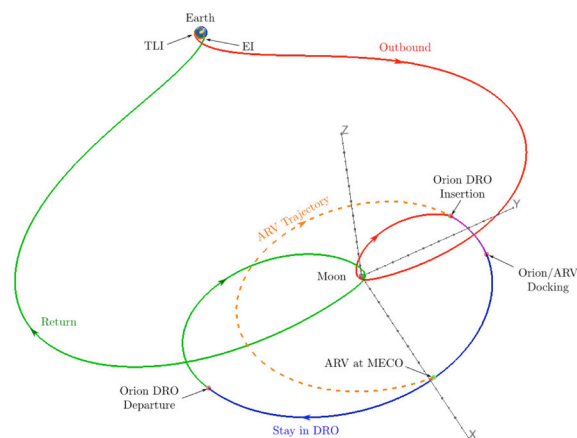


Fig. V: Notional concept of a lunar distant-retrograde-orbit trajectory.

tem developments that will be required. By investing in the launch vehicle as the first development, NASA will enable test flights and near-term exploration—and potentially game-changing robotic science missions and uniquely large space hardware—while the other systems are being developed concurrently. Subsequent developments will include landers, habitats, and power-generation systems.

Plans currently under evaluation call for the initial flights of SLS to send an Orion MPCV into lunar orbit. The first of these flights, Exploration Mission-1 (EM-1) would launch an uncrewed MPCV, and the follow-up flight, Exploration Mission-2 (EM-2), would repeat the mission with a crewed Orion (Fig. V). A lunar orbit trajectory could support NASA's plans for carrying out an asteroid rendezvous mission. If plans to redirect a small asteroid into lunar Distant Retrograde Orbit (DRO) can be completed prior to EM-2, that mission could involve a rendezvous with the asteroid and collection of material samples by the astronauts aboard Orion. Otherwise, EM-2 would consist of a crewed flight of Orion, in preparation for a later flight when the asteroid redirection is complete. The Orion MPCV is designed for beyond-Earth-orbit human spaceflight, with such supporting capabilities as a thermal protection system designed for high-velocity Earth-atmosphere reentry from deep space, and SLS is uniquely capable among contemporary vehicles to provide the mass-lift needed to launch Orion on these missions.

In addition to those planned missions, SLS and Orion could support other human exploration missions in and around cislunar space, including crewed

flights into low lunar orbit and to the Earth-Moon Lagrange points. Studies have also shown that with one additional development derived from existing technologies and systems, SLS could be used to launch a deep space habitat into lunar space that could then be crewed using the Orion MPCV.

Beyond cislunar in-space missions, options exist for furthering exploration towards Mars. The NASA Authorization Act of 2010, which outlined requirements for SLS, also included a capabilities-driven-framework approach to space exploration, intended to open up vast opportunities for new destinations, including near-Earth asteroids and Mars. This followed the 2009 Review of U.S. Human Spaceflight Plans Committee Report.² The committee that produced that report, chaired by Norman Augustine, recommended a flexible path as one of three potential options for human exploration beyond Earth orbit.

A flexible path, in the words of the Augustine Commission, represents a different type of exploration strategy, one that would allow humans to learn how to live and work in space, to visit small bodies, and to work with robotic probes on planetary surfaces. It would provide the public and other stakeholders with a series of interesting “firsts” to keep them engaged and supportive. Most important, because the path is flexible, it would allow for many different options as exploration progresses, including a possible return to the Moon’s surface, missions to near-Earth objects or the moons of Mars, or a continuation directly to the Martian surface. SLS is intended to serve as a key cornerstone of the flexible path approach to space exploration, and the SLS architecture and block design approach reflect this strategy.³

The International Space Exploration Coordination Group (ISECG), consisting of 12 space agencies, including NASA, from nations around the world, has identified three primary “mission themes” for precursors

towards human missions to the surface of Mars. Just as the development of SLS as the first step in a larger exploration architecture enables early flights while other systems are being developed, so too does the ISECG approach enable earlier exploration while working towards Mars. Those themes, as outlined in the Global Exploration Roadmap (GER), are exploration of a near-Earth asteroid, extended duration crew missions in the lunar vicinity, and humans to the lunar surface.⁴ The first two would involve sending humans farther into space than they have ever been before and would require the development of the in-space systems, such as habitation and propulsion, that will eventually be needed for humans to travel through space to get to Mars. The latter theme would involve establishing a long-term human presence on the lunar surface, and would require the development of surface systems, including surface habitats and power-generation systems that will be needed for human exploration of the surface of Mars. Since SLS was designed to provide the capabilities necessary to support human missions to Mars, it also provides the capability to support incremental missions leading to that goal, and the GER recognizes SLS as an enabling resource for its mission themes.

Design of SLS as an enabling capability for human missions to Mars was based on meeting the requirements outlined in NASA’s Mars Design Reference Architecture 5 (DRA5), the Agency’s most-recently completed study of options for human Mars exploration.⁵ The study outlines all of the systems and supplies that will be needed to execute a crewed Mars landing and identifies the Earth-orbit-departure mass for those payloads as being approximately 825 metric tons, double the mass of the International Space Station. Among the largest single systems required will be the in-space propulsion, for which the DRA5 identifies multiple options, including traditional chemical, nuclear thermal, nuclear electric, and solar electric propulsion (Fig. VI). Regardless of the option chosen, launching the in-space propulsion system as defined by DRA5 will require the mass- and volume-lift capability provided only by an evolved SLS, with a minimum mass-lift requirement of 105 t and a

² NASA Authorization Act of 2010: Review of U.S. Human Spaceflight Plans Committee Report, October 22, 2009: http://www.nasa.gov/pdf/396093main_HSF_Cmte_Final_Report.pdf

³ “Voyages: Charting the Course for Sustainable Human Space Exploration,” June 2012, <http://www.nasa.gov/exploration/whyweexplore/voyages-report.html#.UhZwPOBcTh4>

⁴ “The Global Exploration Roadmap,” August 2013, http://www.nasa.gov/sites/default/files/GER_2013_for_release.pdf

⁵ Mars Design Reference Architecture 5.0, July 2009: http://www.nasa.gov/pdf/373665main_NASA-SP-2009-566.pdf

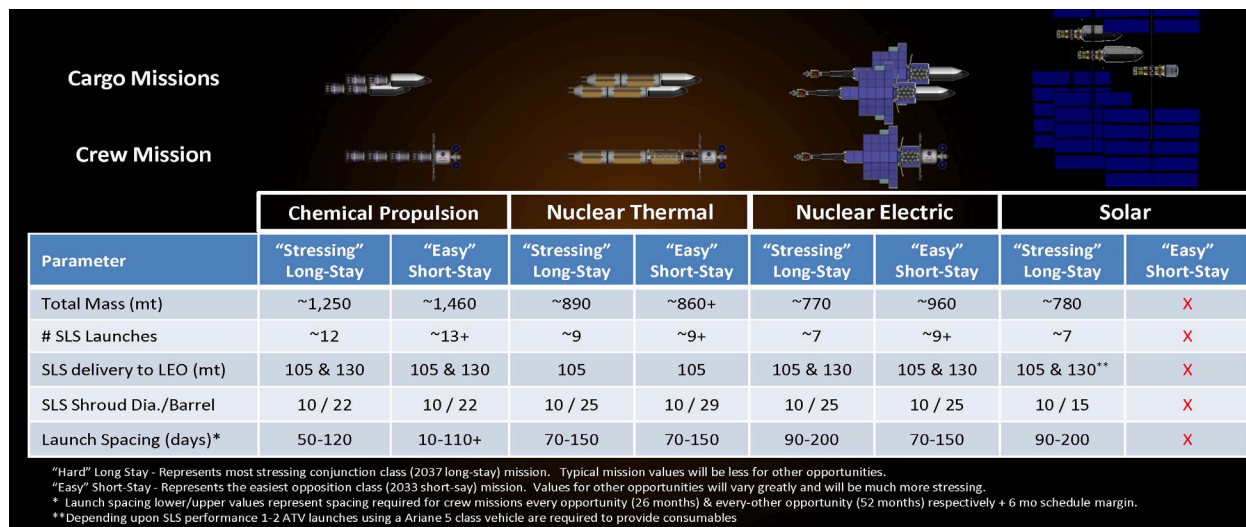


Fig. VI: In-space propulsion options for crewed Mars surface mission.

minimum volume lift capability of a 10 m fairing. Even for non-monolithic Mars-mission hardware that does not require launch on a single rocket, SLS offers substantial benefits. Breaking systems down into separately launched components requires adding mating adapters, which would increase mass, complexity, and mission risk. Studies also show that decreasing the number of launches also substantially decreases mission risk; launching payloads for a Mars mission via an SLS-class vehicle can double the probability of mission success over a contemporary EELV approach.

In addition to the human spaceflight utilization options outlined by NASA and its partner agencies, private entities have also begun identifying enhancing or enabling capabilities of SLS for human operations and exploration. Inspiration Mars, an organization working toward a crewed flyby of Mars in 2018, has identified substantial potential benefits of SLS for that mission, and Bigelow Aerospace has likewise identified substantial potential benefits of SLS for the launch of a 2,100 m³ space habitat that would offer double the pressurized volume of the International Space Station.

V. ROBOTIC SCIENCE UTILIZATION

While designed around the goal of enabling human exploration of the solar system, the mass and volume lift capability Space Launch System will provide to fulfill that charter will also provide

game-changing benefits for a range of promising space science missions.

The primary consideration for most robotic space missions has been the need to fit the payload inside existing launch vehicle fairings, which constrain spacecraft mass and size and often result in complex, origami-type folded designs that increase vehicle complexity and risk. SLS provides enough space to allow designers to relax volume constraints and concentrate on developing the instruments necessary to accomplish the primary science mission. Another constraint for current science missions is the limit on C3 available to send spacecraft to BEO. The additional energy SLS offers reduces mission time, thereby reducing power requirements as well as the amount of time that scientific instruments are exposed to space (Fig. VII). While commercial



Fig. VII: C3 comparison of SLS to EELVs

launchers have and will continue to serve as the workhorse for many of NASA's science missions, the spacecraft often have to make multiple gravity-assist maneuvers around inner planets before reaching the velocity needed to reach outer planets such as Jupiter or Saturn. These maneuvers increase mission times by years and increase risk to onboard instruments because of the extended time in the space environment.

Primary advantages of SLS for robotic science missions include:

- Volume and mass capability and less-complex payload designs needed to fit in the fairing, leading to increased design simplicity.
- Fewer deployments and critical operations, leading to increased mission reliability and confidence.
- High-energy orbit and shorter trip times, leading to less expensive mission operations and reduced exposure to the space environment.
- Increased lift capacity and payload margin, resulting in less risk.

The SLS team has participated in technical interchange meetings with members of the science community to begin a dialogue on the vehicle's benefits for future missions and to better define how the

rocket could enable them. Fully taking advantage of the mass and volume capacity SLS offers will require spacecraft designers and mission planners to change fundamental assumptions about spacecraft and mission design. However, if put to its greatest advantage, SLS could facilitate single-launch missions to the outer solar system, including first-ever sample return missions to Mars, Jupiter/Europa, and Saturn/Titan (Fig. VIII).

To inform those conversations, NASA's Marshall Space Flight Center's Advanced Concepts Office performed an SLS Utilization Study, conducted as a follow-on to earlier Constellation-era decadal surveys, astronomy workshops, and planetary workshops, investigated arenas of opportunity that extend beyond human exploration goals into other areas of space exploration.⁶ The initial process of the study was to perform a literature survey of all potential arenas in order to identify key mission goals and objectives. The literature survey included the various decadal surveys, previous utilization efforts conducted

⁶ The National Academies Press, "Launching Science: Science Opportunities Provided by NASA's Constellation System," 2008: http://www.nap.edu/openbook.php?record_id=12554&page=R1

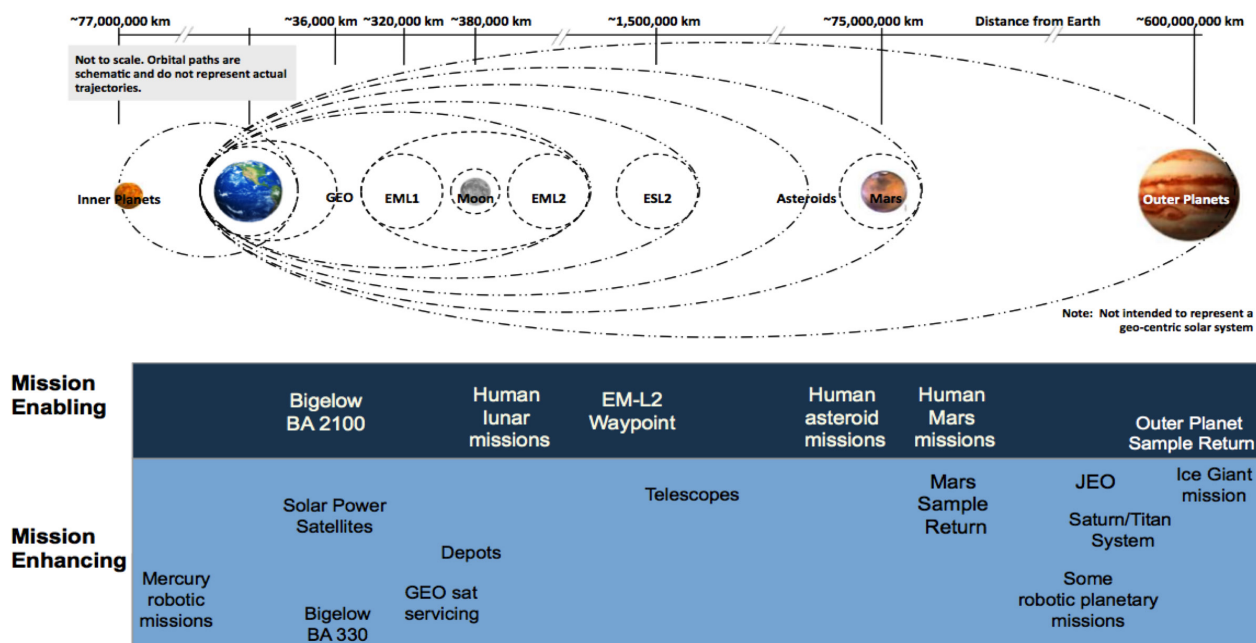


Fig. VIII: Summary of SLS mission capabilities

under the Constellation Program, and other special studies. Missions were organized and classified into arenas based on their destinations and goals. Over 40 potential mission candidates were identified, for destinations including inner planets, outer planets, Mars, near-Earth objects and the Earth-Moon Lagrange (EML) Points and Earth-Sun Lagrange (ESL) Points.⁷

Among the candidates identified in that study was returning a sample from the surface of Mars, which has been a long-term goal for the Mars program for some time. A 2011 National Research Council (NRC) planetary science Decadal Survey concluded that a Mars Sample Return (MSR) mission is not only a top science priority, but also a good opportunity to blend the science and human spaceflight elements of NASA.⁸

The SLS Utilization Study identified MSR as a highly regarded potential mission SLS could enable or enhance. Two primary areas that the study focused on were mission complexity and sample size. The Mars Program Planning Group (MPPG) has recognized that the SLS may provide a “single shot” MSR opportunity.⁹ The MPPG, chartered to provide options that integrate science, human exploration, and technology at an Agency level with Mars exploration as a common objective, found that a sample return orbiter can be integrated into a single launch with a Mars Ascent Vehicle (MAV) lander or combined/co-manifested with other missions.¹⁰ An SLS-en-

hanced Mars sample return could also be executed as a two-launch effort in connection with the Mars 2020 rover project, which is planned to cache material samples for future retrieval. A baseline approach to retrieval would require two additional launches, one to bring the samples from the surface to Martian orbit, and another to return them from orbit to Earth. SLS could combine those two launches into one, expediting the sample return and increasing the probability of mission success.

Since the completion of the SLS Utilization Study, the Program has worked with the NASA science community to further refine concepts and requirements for some of the identified missions and to discuss opportunities for future collaboration. One such mission is an advanced-technology large-aperture space telescope. Although such a mission could likely be decades away, concept evaluation has demonstrated potential benefits of a large 8.4 or 10 m SLS payload fairing for the science community. Such a fairing would enable the launch of a large aperture (potentially 16 to 20 m) telescope that would be able to make spectroscopic observations of exoplanets, enabling a search for life in other solar systems. Concept evaluations of such a project have also identified opportunities for further collaborations between science and human exploration systems in the form of assembly and servicing of an observatory in deep space.

Another mission that has been the subject of further concept definitization with the science community is a Europa Clipper Pre-Project. Europa is believed to have a subsurface ocean, covered by a layer of water ice, that contains twice as much water as Earth, making the Jovian moon a high-interest target in the search for signs of past or present life on other worlds, and a high priority of the planetary science Decadal Survey. Collaborative evaluation has revealed that by enabling a direct trajectory outbound flight to the Jovian system versus a Venus-Earth-Earth gravity assist (VEEGA) trajectory required by a baseline EELV approach, SLS could reduce transit time from 6.4 years to 1.9 years (Fig. IX). Not only does this greatly expedite science return from the mission, it also has a corresponding impact on mission operation cost, potentially eliminates mass impacts of designing for the hotter environment of an inner-solar system flyby, eliminates permitting requirements for flyby of Earth with a radioisotope generator, and potentially allows for a longer science

⁷ NASA Human Exploration and Operations Mission Directorate: “Exploration Planning, Partnerships, and Prioritization Summary,” March 6, 2012: http://www.nasa.gov/pdf/630147main_4-Olson_Planning%20Partnerships%20Priorities%20030612_508.pdf

⁸ National Research Council, “Visions and Voyages for Planetary Science in the Decade 2013-2022,” 2011: http://solarsystem.nasa.gov/multimedia/downloads/Vision_and_Voyages-FINAL1.pdf

⁹ National Research Council, “Visions and Voyages for Planetary Science in the Decade 2013-2022,” 2011: http://solarsystem.nasa.gov/multimedia/downloads/Vision_and_Voyages-FINAL1.pdf

¹⁰ Mars Program Planning Group Report Summary, September 25, 2012: http://www.nasa.gov/pdf/691580main_MPPG-Integrated-v13i-Summary%20Report-9-25-12.pdf

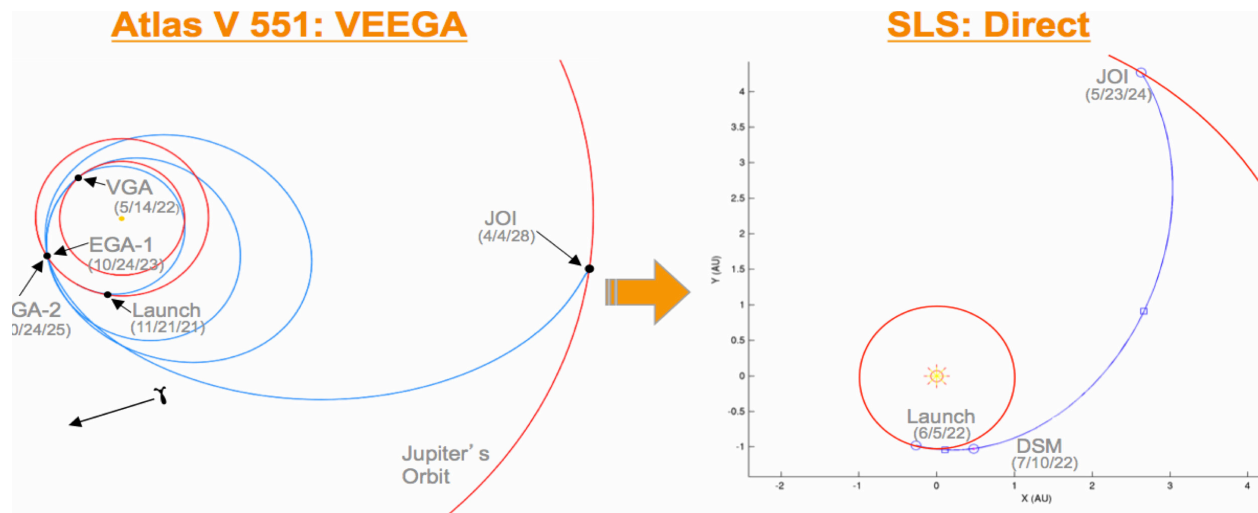


Fig. IX: Earth-to-Europa trajectory comparison for Atlas V and SLS

mission at the destination with quicker science return. While SLS would offer trade space for a spacecraft with much greater mass by longer transit time, this evaluation chose to focus on spacecraft mass compatible with an EELV baseline and decreased transit. Even so, SLS would offer a substantial mass margin over the EELV baseline without an impact to the reduced transit time. By reducing transit time to the outer solar system to a third, SLS could enable an iterative approach to exploration to those targets similar to what is currently used for robotic exploration of Mars.

VI. SUMMARY

Through the development and operation of the Space Launch System, NASA is creating a new international capability that will serve as a cornerstone for a wide variety of utilization of space for decades to come, complementing contemporary systems for human operations in low Earth orbit by enabling ambitious missions that would not otherwise be possible (Fig. X). Following its first flight, SLS will return humans to deep space for the first time in decades, beginning a series of exploration missions that will lead to Mars. That same capability will also enable a wide variety of other missions, including science spacecraft that will reveal an unprecedented wealth of knowledge about our solar system and universe.



Fig. X: Artist's concept of SLS 130 t vehicle launching from the Kennedy Space Center



NASA's Space Launch System: *One Vehicle, Many Destinations*

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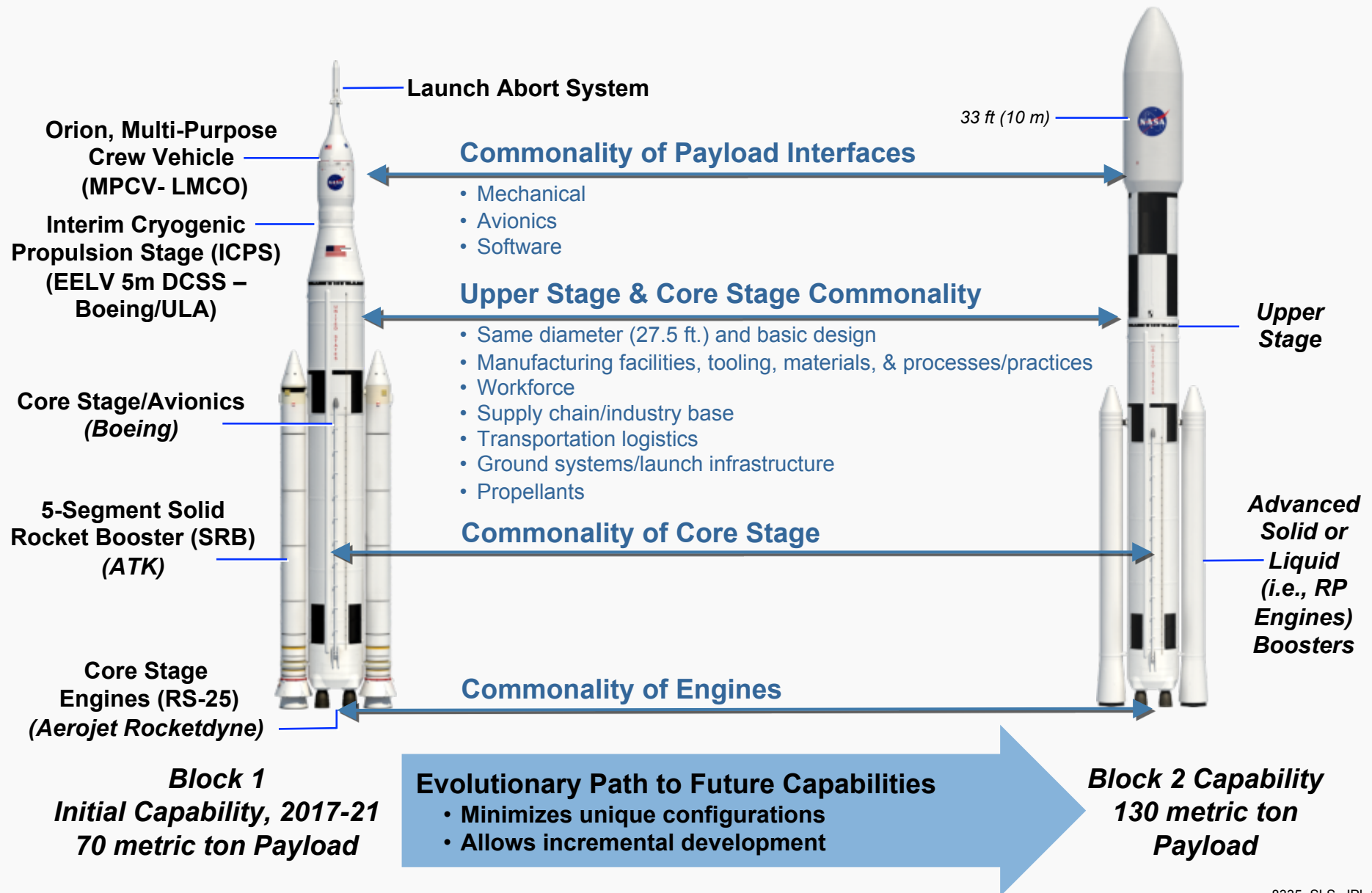
NASA Marshall Space Flight Center
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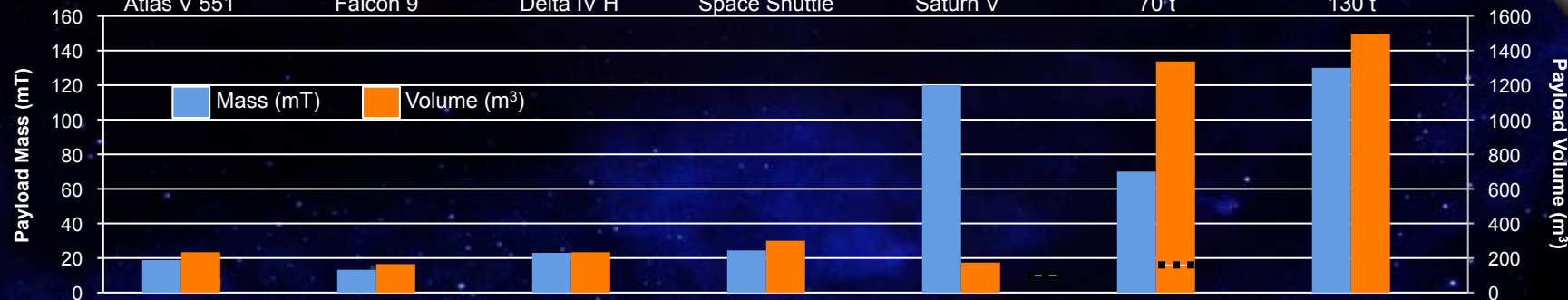
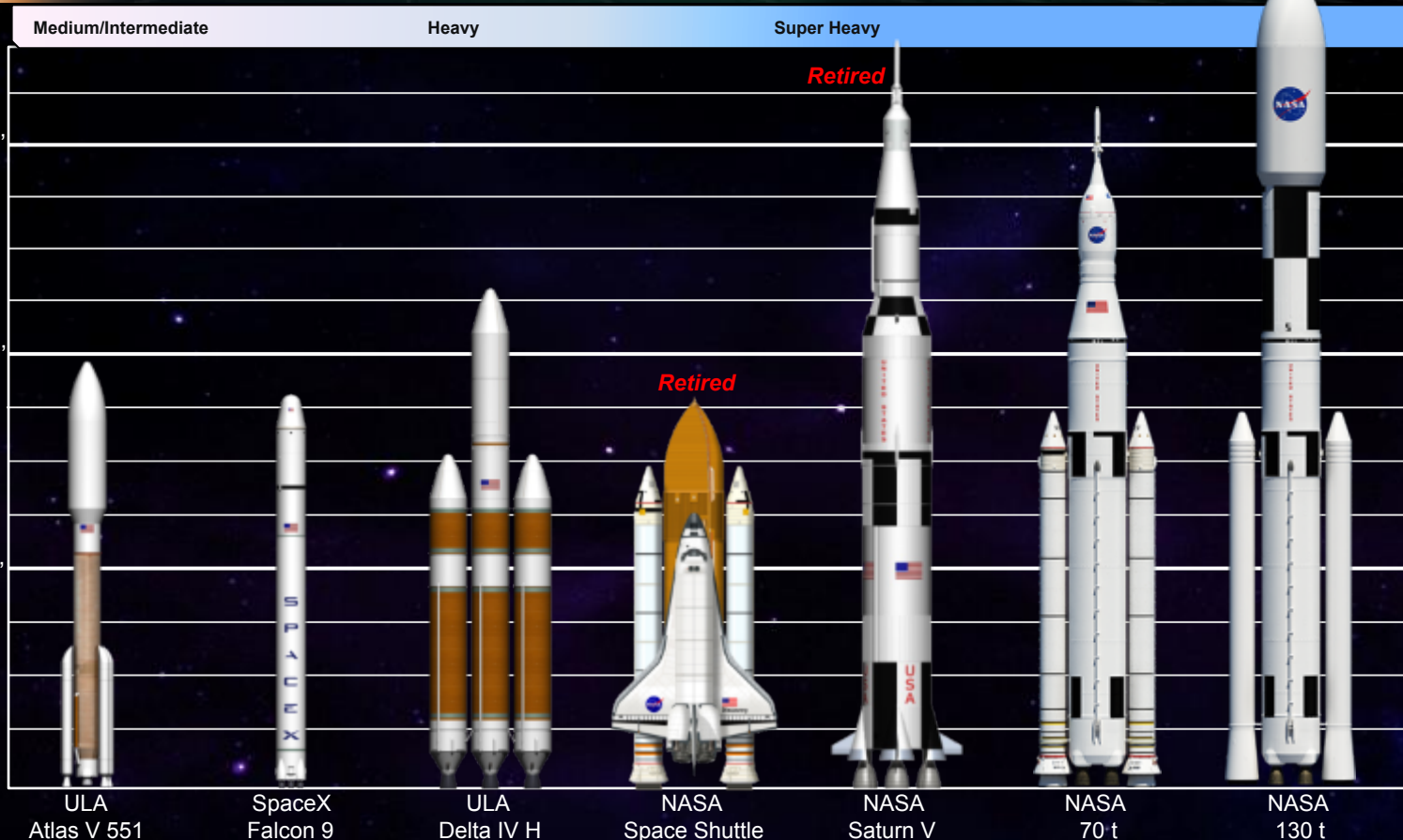
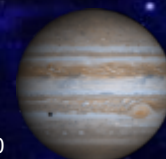
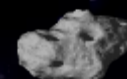
Space Launch System



SLS Block Commonality



Most Capable U.S. Launch Vehicle

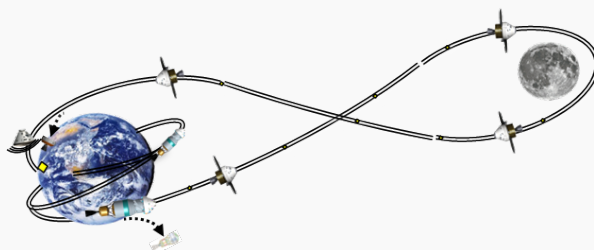


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EM-1 Mission Options

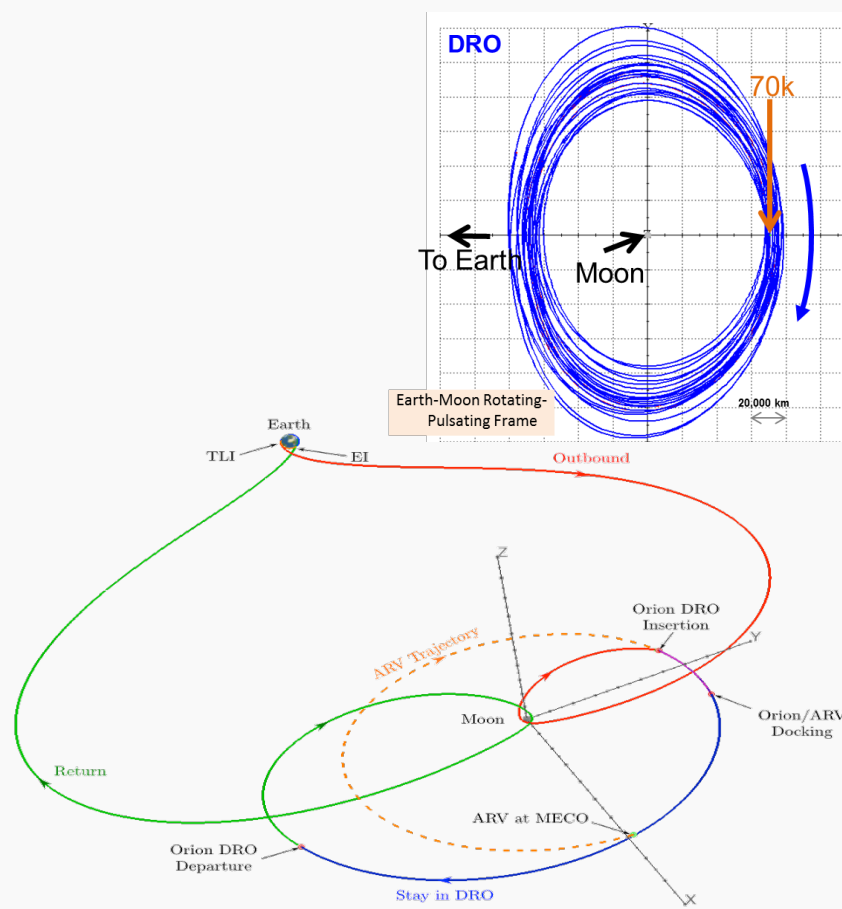


- **EM-1 Lunar Flyby**



- **EM-1 Lunar Distant Retrograde Orbit**

- Round-Trip Transfer to a Lunar DRO
 - DRO Initial $A_x = 70,000$ km (fixed)
 - Powered lunar gravity assists (minimum 100 km altitude) on outbound and return
- Uncrewed rehearsal of the ARCM mission
- No change to Program Flight Test Objectives (FTOs)
- No hardware impacts to the programs



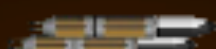
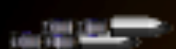
Mars Architecture Requirements



CAUTION

"Easy" short-stay cases denoted here represent best of class (cherry picked). All other mission opportunities will result in higher mass.

Cargo Missions



Crew Mission



	Chemical Propulsion		Nuclear Thermal		Nuclear Electric		Solar	
Parameter	"Stressing" ¹ Long-Stay	"Easy" Short-Stay	"Stressing" ¹ Long-Stay	"Easy" Short-Stay	"Stressing" ¹ Long-Stay	"Easy" Short-Stay	"Stressing" ¹ Long-Stay	"Easy" Short-Stay
Total Mass (mt)	~1,250	~1,460	~890	~860+	~770	~960	~780	X
# SLS Launches	~12	~13+	~9	~9+	~7	~9+	~7	X
SLS delivery to LEO (mt)	105 & 130	105 & 130	105	105	105 & 130	105 & 130	105 & 130**	X
SLS Shroud Dia./Barrel	10 / 22	10 / 22	10 / 25	10 / 29	10 / 25	10 / 25	10 / 15	X
Launch Spacing (days)*	50-120	10-110+	70-150	70-150	90-200	70-150	90-200	X

¹"Hard" Long Stay - Represents most stressing conjunction class (2037 long-stay) mission. Typical mission values will be less for other opportunities.

²"Easy" Short-Stay - Represents the easiest opposition class (2033 short-stay) mission. Values for other opportunities will vary greatly and will be much more stressing.

* Launch spacing lower/upper values represent spacing required for crew missions every opportunity (26 months) & every-other opportunity (52 months) respectively + 6 mo schedule margin.

** Depending upon SLS performance 1-2 ATV launches using a Ariane 5 class vehicle are required to provide consumables

SLS Benefits for Other Missions



◆ SLS Enables Exploration Missions

- **Greater volume and mass capability/ margin**

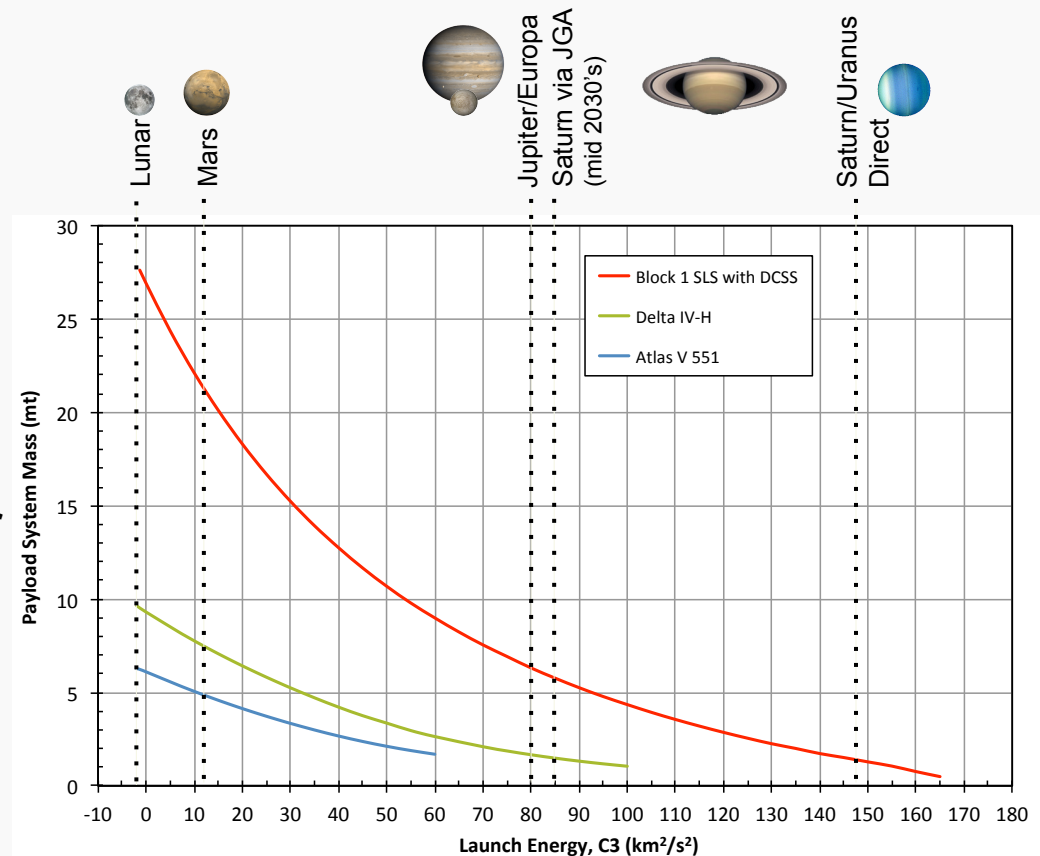
- Increased design simplicity
- Fewer origami-type payload designs needed to fit in the fairing

- **Single launch of multiple elements means fewer launches, deployments, and critical operations**

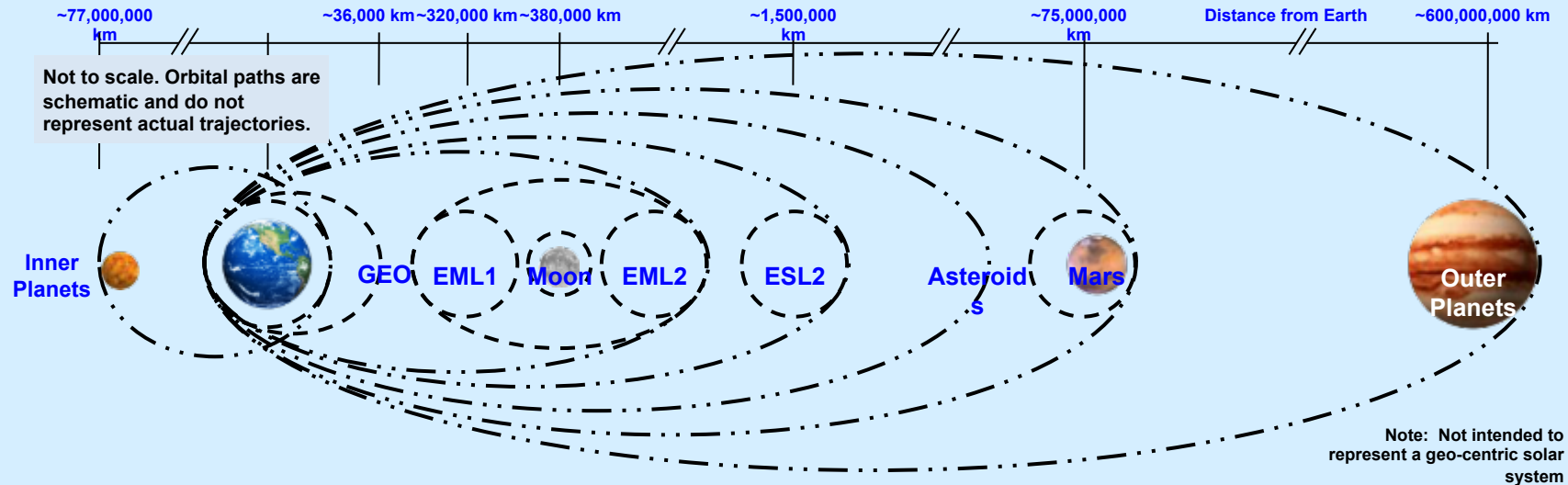
- Simplifies on-orbit operations
- Reduced risks and hazards

◆ SLS investment can be leveraged for other missions requiring large volume or mass, or reduced trip times

- Deep Space Exploration
- Planetary Landers
- Human Habitats
- Great Observatories
- Space Solar Power
- Outer Planet Missions
- Department of Defense/NRO Payloads



SLS Mission Capabilities



Enabling
(Missions SLS is designed to enable)

High Benefit
(Mass, volume and trip time make SLS very attractive)

Enhancing
(Other approaches exist, e.g., multiple launches)

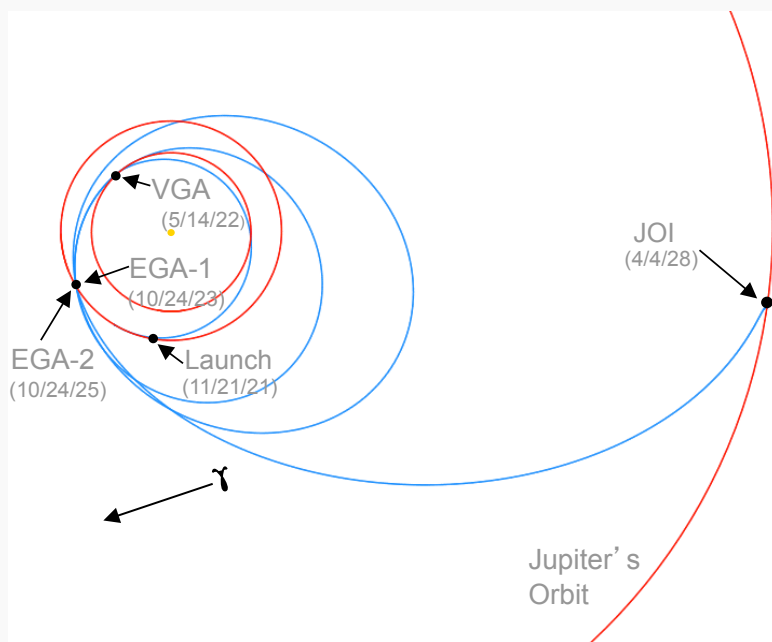
No Benefit
(No foreseeable benefits from SLS)

	Human lunar missions	EM-L2 Habitat	Human asteroid missions	Human Mars missions	Outer Planet Sample Return
	Solar Power Satellites	Telescopes		Mars Sample Return	JEO Saturn/Titan System Ice Giant mission
Mercury robotic missions	Bigelow BA 2100 Bigelow BA 330	Depots GEO sat servicing			Some robotic planetary missions
Venus robotic orbiters or landers	Comm sats LEO small sats	Lunar robotic orbiters or landers			

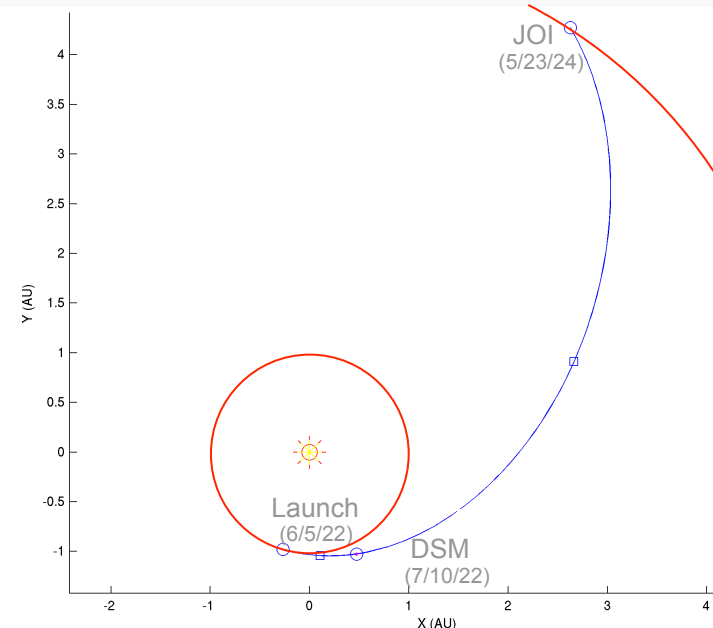
Europa Mission Benefits



Atlas V 551: VEEGA



SLS: Direct



SLS Advantages

- Time Of Flight: -57%
- Avoids Venus thermal environment
- Eliminates Earth flyby nuclear safety concern
- 45% mass margin for current concept

Time of flight:	6.4 years
Earth Flybys:	2
Sun Closest Approach:	0.6 AU
C3:	15 km ² /s ²
Launch Capability:	4494 kg (41% Margin)

Time of flight:	1.9 years
Earth Flybys:	0
Sun Closest Approach:	1.0 AU
C3:	82 km ² /s ²
Launch Capability:	6087 kg (45% Margin)

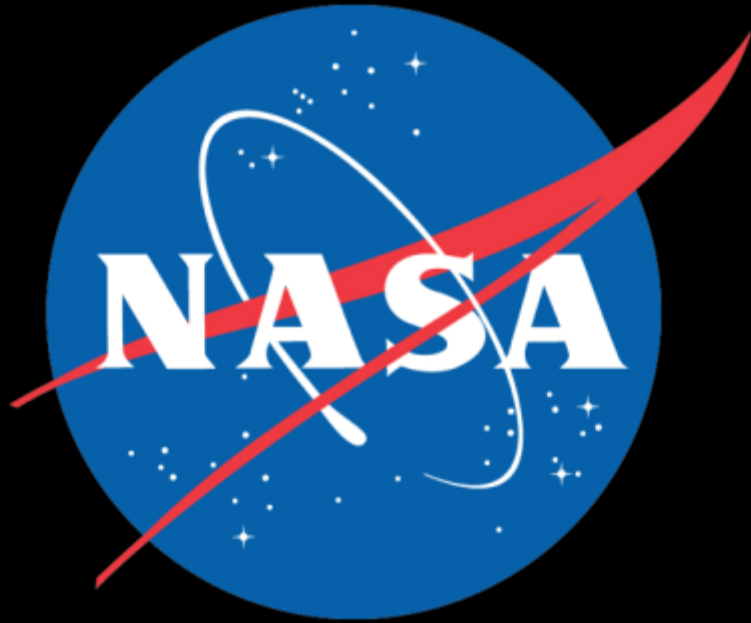
Summary



- ◆ **SLS provides capability for human exploration missions.**
 - 70 t Block 1 configuration enables EM-1 and EM-2 flight tests.
 - Evolved configurations enable missions including humans to Mars.

- ◆ **SLS offers unrivaled benefits for a variety of missions.**
 - 70 t Block 1 provides greater mass lift than any contemporary launch vehicle; 130 t offers greater lift than any launch vehicle ever.
 - With 8.4m and 10m fairings, SLS will offer greater volume lift capability than any other vehicle.
 - Initial ICPS configuration and future evolution will offer high C3 for beyond-Earth missions.

- ◆ **SLS continues to study potential cooperation with SMD and other users.**
 - SLS offers capability to launch larger payloads into low Earth orbit.
 - For planetary missions, SLS offers reduced transit times and greater mass margins.
 - SLS enables unique payloads not possible using other vehicles.



*Somewhere, something
incredible is waiting to
be known.*

— Carl Sagan

For More Information

www.nasa.gov/sls

www.twitter.com/nasa_sls

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